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Not so gameful: A critical review of gamification in mobile energy applications

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ABSTRACT

In order to help mitigate climate change and reduce the health-related consequences of air pollution, consumers need to be empowered to make better and more effective decisions regarding energy use. Utilities, government, and commercial entities offer numerous programs and consumer products to help individuals set or reach goals related to energy use. Many of these interventions and products have related apps that use gamification in some capacity in order to improve the user experience, offer motivation, and encourage behavior change. We identified 57 apps from nearly 2400 screened apps that both target direct energy use and employ at least one element of gamification. We evaluated these apps with specific focus on gamification components, game elements, and behavioral constructs. Our analysis shows that the average energy related app heavily underutilizes search engine optimization, gamification components, and game design elements, as well as the behavioral constructs known to impact energy-related decision-making and behavior. Our findings offer several insights for the design of more effective energy apps.

1. Introduction

Reducing emissions of the energy sector is critical to solving some of our greatest societal problems, including carbon emissions leading to climate change and air pollution effects on human health. Energy efficiency, renewable energy, and transportation choices are all important aspects of addressing these issues. However, it is not clear that most people know which actions to take to effectively reduce energy consumption or reach energy-related goals [1,2]. The persistent energy-efficiency knowledge gap has been attributed to a number of causes, including misplaced anchor points (not understanding how much energy different actions require), information overload (too many actions and lists of things to do), and a lack of accurate and actionable information among others [2–4]. Similar barriers stymie residential solar photovoltaic (PV) adoption, though from overestimation of costs in a rapidly changing marketplace [5]. Additionally, information search costs, risk aversion, and lack of uniform access to system financing slow solar adoption rates [6,7]. Transportation can be made more efficient through reduced mileage, use of more efficient vehicles, or a move toward electric vehicles (EV), though trends in the United States have fluctuated and recently moved in the opposite direction on the first two behaviors [8,9], while one survey found 60% of Americans are not even aware of plug-in electric vehicles [10]. This contrasts sharply with European consumers, where a recent poll shows 40% expect their next car to be electric [11]. This points to the critical role of consumer decision making in creating a sociotechnical system that reduces carbon emissions and a need to increase engagement to address the needed changes in energy behaviors.

Gamification, i.e., "the use of game design elements in non-game contexts" [12], is frequently proposed as a means of bridging information gaps, increasing learning, and motivating behavior change [13–19]. As the energy sector moves toward increased customer engagement (e.g., through smart meters, prosumers, and competitive retail markets) and third parties offer an increasing number of products targeted toward residential energy use (e.g., smart home connected devices, energy management, solar PV), the number of *apps* available – from solar PV to utility-sponsored billing and data apps – is increasing. Many of these apps employ gamification as a means to engage customers or encourage energy-efficient behavior.

A nascent and growing body of literature supports the effectiveness of gamification for energy behavior change, but also reveals immaturity in the design and robustness of these efforts. Typhina's 2015 review of eco-apps found that only 11 of the 290 apps listed on the EPA's website offered a "learning experience that is unlike learning from a book, in-person presentation, or website" [20]. Grossberg et al. reviewed over 300 utility-run behavior programs in the U.S., identifying 53 that used

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games or gamification [15]. They selected 22 for case studies and indicate that only 6 of those are smartphone enabled, and it is unclear how many have online components. They find gamified energy efficiency programs can achieve savings of 3–10% depending on how targeted the program is, though the sample size for this study was limited (n = 9) and included real-world games, rather than being restricted to apps [15]. AlSkaif et al. developed a framework for gamification in the energy domain and identified 19 European programs implementing the key design elements; however, they do not discuss the outcomes of these programs [21]. In a systematic review of studies on the effectiveness of both gamification and serious games (i.e., games designed for a primary purpose other than entertainment) in pro-environmental behavior, Morganti et al. [22] found only 10 studies meeting the inclusion criteria covering widely varying types of games; however, they concluded that research results of those 10 studies point to games and gamification "fostering energy-saving behavior." Johnson et al. recently reviewed the literature for empirical support for gamification and serious games in domestic energy use, finding 26 research articles. They conclude that the evidence supports the value of gamification and serious games for behavior, cognition, and learning for domestic energy consumption, but based on limited empirical evidence, thus warranting additional research [23]. Both Morganti et al. and Johnson et al. reviewed studies from the international body of literature, and still found a limited number of systematic, robust studies of gamification best practices. This limited body of research indicates that app developers in every market face difficulty in determining effective gamification strategies. For the purposes of this paper, we will focus on the U.S. market.

The small sample sizes, limited number of commercially-ready products (i.e., apps that can reach beyond a local or pilot audience), and paucity of systematic studies in the energy sector contrasts sharply with the healthcare sector. The healthcare sector has successfully deployed apps targeting health management and behavior change, so much so that "health and fitness" apps have their own category on the Apple App Store. Energy-related apps neither have their own category, nor obviously fit into any particular primary category, making them difficult to find. Additionally, Baranowski et al. identified studies on 25 video games targeting health-related behavior change by 2006, before the App Store even came online; most of these studies were randomized control trials studying the effectiveness of health interventions and the effectiveness of apps [24]. More recently, Lister et al. published an analysis of the state of gamification in health apps, looking at the impact of the use of gamification components, game elements, and behavioral constructs [25]. They found 261 health related apps of which 132 used gamification. Edwards et al. also studied gamification in health apps and found 64 of 1680 that met their inclusion criteria (e.g., using gamification techniques, targeting physical health behavior, and having a customer rating), using an average of 14 behavior change techniques each [26]. This indicates a much more mature body of work on both the effectiveness and use of gamification in healthcare that can inform and guide energy gamification efforts.

Our primary goal in this paper is to understand the extent to which gamification, game design, and behavioral constructs are deployed in energy apps. We also examine the impact of using these on user satisfaction with and popularity of energy apps. The extent to which energy apps drive behavior change related to energy is beyond the scope of this study, since we do not have data on outcomes of the apps.

The rest of the paper is structured as follows. We first present our methodology, focusing on identification of behavioral and gamification constructs and on the search process used to sample the apps used in this study. Next, we present results, focusing on the use of various gamification and behavioral constructs in the identified sample of apps and how the use of such constructs impacts app ratings. Finally, we present a discussion of the obtained results, followed by conclusions that emerge from this study.

2. Methodology

Our methodology is divided into three topics. First, we identify the key constructs for assessing the use of gamification components, game elements, and behavioral constructs in energy-related apps following a methodology similar to Lister et al. [25]. Next, we discuss the selection criteria and methods for identifying the energy apps analyzed in this paper. Finally, we discuss the variables and constructs used in our analysis.

2.1. Identifying key constructs

In order to evaluate the energy apps, we first determined which gamification components and game elements (defined below) are most essential. Hamari et al. conceptualize three main parts of gamification in their review: (1) the implemented motivational affordances, (2) the resulting psychological outcomes, and (3) the following behavioral outcomes [27]. Based on their analysis, they identify 10 game-like *motivational affordances*: points, leaderboards, badges/achievements, levels, stories/themes, clear goals, feedback, rewards, progress, and challenge. Lister et al. only find six core components of gamification common in health, so we use Hamari's longer, more general list as the more extensive inventory, which we refer to as the *gamification components*.

Game elements are the design elements used in hedonic games. These differ from gamification components, which focus primarily on motivational affordances. For *game elements*, we use the same list as Lister et al. adapted from Reeves & Read [28] and Deterding et al. [12] resulting in 11 elements: self-representation with avatars, three dimensional environments, narrative context (i.e., story), feedback, reputations (divided into rank/leaderboard and levels), marketplaces, competition, teams, communication systems, and time pressure. As gamification is defined as the use of game design elements (in non-game contexts), it follows that there is some overlap between the gamification components and game elements, including feedback, leaderboard, levels, and story. Gamification tends to omit the more sophisticated game elements in terms of implementation, such as avatars, marketplaces, and three-dimensional environments. Despite overlap between what constitutes gamification components and game elements, using both gamification components and game elements in our analysis allows for more exhaustive coverage of relevant factors, combining both the motivational affordances leading to behavior change that gamification focuses on and the hedonic elements of games that lead to an engaging and fun user experience.

To develop a list of behavioral constructs, we start with Wilson & Dowlatabadi [29] who review the theories behind residential energy decision-making. We then narrow down to key theories in the literature, with a focus on Steg & Vlek's [30] framework for pro-environmental behavior and Wolske et al.'s [31] framework on solar energy adoption, both of which integrate multiple theories to reach a more comprehensive understanding of the drivers of behavior. Six theoretical approaches, resulting in 13 total constructs, stand out for their relevance and frequent inclusion in the literature: utility maximization theory, behavioral economics, diffusion of innovations framework, cognitive dissonance theory, theory of planned behavior, and value-belief-norm theory.

Utility maximization relies primarily on access to information and cost-benefit analysis. Behavioral economics adds to this a number of additional influences on decision-making strategies, such as framing, anchoring, mental accounting, and cognitive burden [32]. Diffusion of innovations framework addresses the process by which an innovation (in this context an innovation can be a behavior/practice or technology) diffuses through society [33]. Factors influencing diffusion or adoption of a practice or technology include information channels (e.g., media, peer-to-peer), adopter characteristics (e.g., socio-demographic, perceptions of technology), innovation factors (relative advantage,

compatibility, complexity, trialability, and observability), and social context (norms, trust in information channels, or social networks). Cognitive dissonance theory states that individuals will make decisions to seek consistency between knowledge, attitudes, and actions [34]. Public commitments to a behavior can be effective in motivating behavior consistent with stated attitudes, whereas low self-efficacy (see Table 1 for definition) may prompt a rejection of information or change in attitude to maintain consistency. The theory of planned behavior states that attitudes, subjective norms, and perceived behavioral control lead to intentions, and that intentions and perceived behavioral control then directly influence actual behavior [35,36]. Finally, value-belief-norm theory states that values lead to beliefs (attitudes) regarding the consequences of a behavior and responsibility to act, which then establish personal normative beliefs toward the behavior [37]. Table 1 pulls together the key constructs from these theories, along with definitions, examples of use, and mapping to the key theories identified as effective in addressing energy-related behavior.

2.2. Selecting energy apps

We collected the sample of apps for our analysis from the U.S. Apple App Store. The criteria for inclusion focused on apps that use at least one gamification component and target direct energy use behaviors, such as energy efficiency and conservation behavior, solar or renewable energy, home energy efficiency upgrades, and efficient transportation. Apps that emphasize indirect energy use, such as carbon footprints, were not sought out, but were included where they met significant elements of the inclusion criteria, such as energy efficiency and conservation behavior change. We collected the sample of apps in the first half of 2017. We found that the energy apps space is neither very dynamic nor growing rapidly. Accordingly, and based on our searches on the App Store again in August 2018, we believe that the results of our analysis will not change significantly even if the small number of more recent apps were to be added to our analysis.

Additionally, our identification of energy apps is restricted to the U.S., because we found that identification of energy apps is challenging without awareness of existing energy programs and difficult to analyze without fluency in the language and the socio-cultural context of the energy system. Within the U.S. both the Apple App Store and Google Play have mature platforms with millions of apps and significant market share. We selected the App Store because it has been around the longest and has quality standards that require more upfront work, which increases the likelihood of having higher quality apps. Using a single platform also provides consistency in the variables as the rules and procedures for reviews, ratings, and included app summaries are consistent. These two boundary conditions (i.e., U.S. and App Store) do introduce some bias, and results may not be fully extrapolatable, but given that reviews of gamification studies found few examples regardless of geography, we anticipate that app developers outside of the US face similar challenges in testing and establishing best practices and that the results will be useful outside of the U.S. as well.

To identify the sample, we started with a training set of apps generated from a general key word search (Google) for “apps” plus one of the following: energy, energy efficiency, home energy monitoring system (HEMS), smart home, utility, electricity, water, green energy, solar, green button, hypermiling, and electric vehicle. We included “water,” because many water apps are utility sponsored or related to conservation, which could provide useful key words for searching the App Store for electric utility sponsored apps or energy conservation apps. This produced a training set of 22 apps (see Supplemental information Table SI-1). The training set was then used to reverse engineer the keywords used by the app developers. This extended list of keywords was then used to search for and identify a broader sample of apps from the App Store. The goal of this approach was to generate a comprehensive list of search terms that avoids keyword bias in our search results and uses keywords used by practitioners.

To reverse engineer the training set keywords, we used AppAnnie, an industry standard tool in app analytics and search engine optimization (SEO) [38]. AppAnnie displays the keywords an app is optimized for within the App Store, ranked by the app’s display index for that keyword. For example, *JouleBug* uses the keywords: joule, sustainable, sustainability, eco, etc., and searching the keyword “sustainability” in the App Store yields JouleBug as the third result. For this study, we included keywords that ranked the training app within the “top 50” returned results. We initially began with the “top 100” results, but there were no marginal benefits. We discarded redundant keywords, keywords clearly aimed to optimize a particular app for misspelled searches, e.g. Nest Home using the keyword “nets,” and keywords that stated the name of the app developer. Finally, keywords that clearly did not relate to the app were not included to account for developers broadly optimizing, e.g., GasBuddy included “organization apps” and “find iphone” as keywords. This process resulted in a total of 79 keywords (see Table SI-2 Keyword Search Terms).

For each of these keywords, we returned the top 50 app matches for a total of 2397 apps, which is lower than the expected number (79 search terms x 50 results = 3950 results) due to many keywords returning fewer than the 50 matches requested. A cursory check of these apps for matching the inclusion criteria (e.g., Truck Puzzles for Toddlers – removed, LES Lighting Electrical Efficiency - retained) resulted in a list of 87 apps for more detailed assessment. These apps were reviewed for meeting the inclusion criteria and including at least one gamification component. After the more in-depth examination, the final sample included 57 apps (see Table SI-3 Energy Apps).

2.3. Defining variables and constructs

Data collected from AppAnnie on the final sample includes the name of the app, first year of development, last year of active development, number of reviews, rating, and price. We evaluated the apps for the use of the 13 behavioral constructs, 10 gamification components, 11 game design elements, and inclusion of integrated devices or technology (e.g., solar panels, smart plug, smart meter, thermostat). We anticipate that apps linked to a device or technology purchase are more likely to be used, thus this is an important control variable.

From this data set, we built index variables for the gamification components (GC), game elements (GE), and behavioral constructs (BC) as the sum of the total number used by the app in each respective category; thus, all components, elements, and constructs were weighted equally in the index variables. Using these index variables, inclusion of an integrated device and year of first development, we built linear regression models for number of reviews and app rating as the dependent variables. We did not use price as a variable, since only one app was not free.

These two variables – app ratings and number of reviews – were selected as indicators of customer satisfaction and app popularity, respectively. However, we note that customer satisfaction does not necessarily indicate that an app is effective in achieving its intended outcomes; one can enjoy an app with no subsequent behavior change. Also, while the number of reviews is expected to correlate with popularity of the app, it may be a proxy for marketing efforts on the part of the app developers. Given these limitations, we explore these variables for providing insights into how inclusion of various gamification and behavioral components impact user engagement with energy apps. After all, an app that is not well received or highly rated is unlikely to be used, and an app that is not used has little potential for impacting energy-related behavior at scale.

3. Results

The earliest year of first development is 2008, and the most recent is 2017. While some apps have not been actively developed since 2009, 34 of the apps have been updated in the last two years. The majority of

Table 1
Behavioral constructs, definitions, examples of use, and mapping to the key energy-related behavior theories. UM = Utility Maximization; BE = Behavioral Economics; DOI = Diffusion of Innovaton; CDT = Cognitive Dissonance Theory; TPB = Theory of Planned Behavior; VBN = Value, Belief, Norm Theory.

Theory constructs	Definition	Example	UM	BE	DOI	CDT	TPB	VBN
General Information	Information designed to increase general knowledge or understanding of costs and benefits of a behavior.	Information about how much energy is used by or saved by an appliance or behavior choice. Information regarding the benefit of a technology, such as LEDs providing better light and lasting longer.	x	x	x	x	x	x
Framing	A cognitive bias based on presentation of information.	Frames may include loss, gain, environmental benefit, or economics. Changing a thermostat could be framed as losing comfort or saving money and reducing environmental impact.		x				
Anchoring	A reference point used in decision-making often based on first information available, introduces cognitive bias.	People will estimate lower energy use and lower cost when prompted to think about a light bulb as an anchor point compared to no anchor given [3].		x				
Mental Accounting	Tendency to create categories for allocating costs.	Placing solar as an investment or as a home improvement project. Mental accounting can also set anchor points relative to the category, e.g. considering cost relative to a utility bill or kitchen remodel.		x				
Cognitive Burden	The perceived cost of searching for and processing information.	Making information and links to additional resources easy to access reduces information search cost. Cost estimating calculators reduce information processing burden.		x				
Communication Channels	Channels through which information flows. Trust in the channel is a critical component.	News media, social media, peer-to-peer, expert, app sponsorship or branding.			x			
Attitude	Attitude is based on behavioral beliefs regarding the costs, benefits, and expected outcomes of a behavior. Personal norms mediate attitudinal beliefs.	Information explicitly targeted to impact attitude. This may not be differentiable from cost/benefit or reinforcing personal norms.			x	x	x	x
Social context	Information or tools that make a behavior easier or more accessible by indicating normative behaviors.	Peer effects, e.g. visibility of rooftop solar, or endorsement of behavior or innovation, e.g. number of likes or reviews.			x	x	x	x
Self-efficacy/ Perceived behavioral control	Belief in one's ability to perform a task in such a way as to achieve the desired outcome. Ability to perform a given behavior influenced by both one's perception of their own ability and actual control to perform the behavior.	Presenting actionable information or skills training. Presenting low barrier behaviors or providing means of reducing barriers, perceived or real. Increasing awareness of financing options for solar to reduce upfront cost.				x	x	
Personal Norms/ Values	Expectations people have for themselves influenced by personal values and social norms.	Information on how behavior impacts self, society, or environment.				x	x	x
Subjective Norm	One's perception of normative behavior and motivation to comply.	Information or social interactions that reinforce normative behaviors, such as 80% of households like yours do this.					x	
Awareness of Consequences	In VBN, performing behaviors consistent with personal norms, i.e. responsibility, is motivated through awareness of consequences that run counter to personal norms.	Information that links actions to a behavior, such as reducing energy usage as saving money (value of thrift) or improving air quality (value of health or the environment).						x
External Context	External barriers to performing a behavior, particularly relevant for high-effort, high-cost, and high-involvement decisions. This can include constraints, such as funds to purchase solar, availability of programmable thermostats, access to solar installers, availability of rebates.	Information or tools that make a behavior easier or more accessible, including increasing access to service providers (e.g., certified solar installers), database of available incentives or product performance information/reviews. Quality of public transport. Integrated automation or "eco" settings. Placing recycle bins next to every trash can.	x	x	x	x	x	x

Note: Constructs that vary slightly, but that are measured or implemented in the same way are grouped.

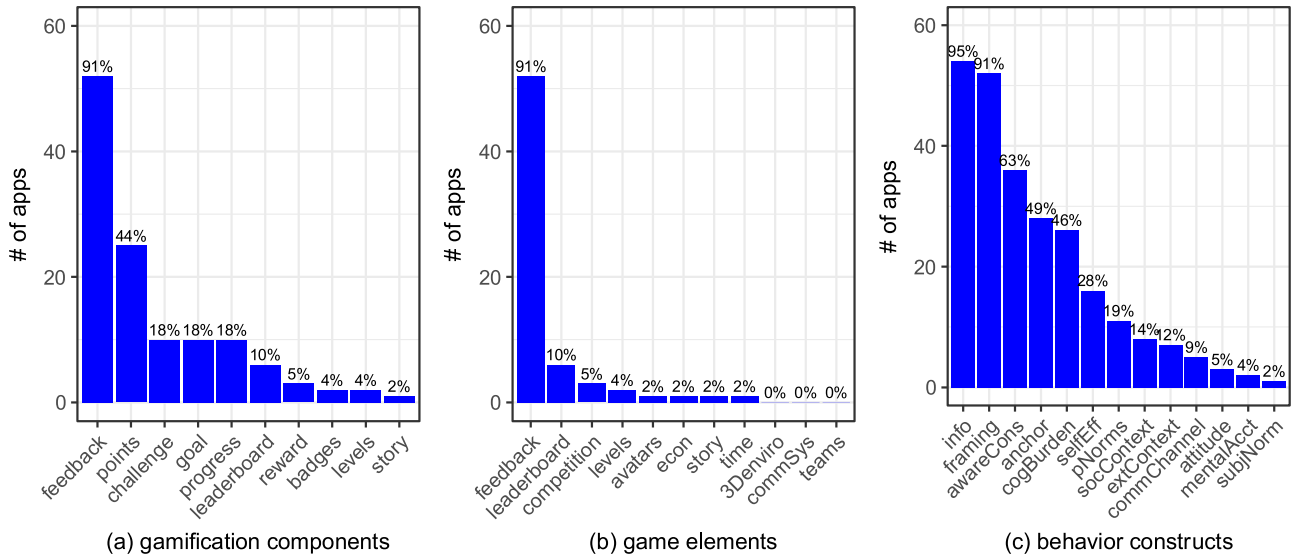

Fig. 1. Summary statistics for (a) gamification components, (b) game elements, and (c) behavioral constructs (see Table 1 for definitions), with total number of apps using the variable on the y-axis and percentage of apps using the variable above. (n = 57).

the apps were developed by third-party entities, whereas nearly 23% (n = 13) were developed or sponsored by utilities. Just over 45% (n = 26) were designed to work with another technology or device, such as a smart utility meter, smart home or home automation products, solar panels, or an electric vehicle. The mean number of reviews received by an app is 65 (sd = 126), and the mean rating is 3.2 out of 5 (sd = 0.96).

Fig. 1 shows the summary statistics for gamification components, game elements, and behavioral constructs. The mean use of gamification components is only 2.1 per app, indicating that gamification components are underutilized as a motivational tool. *Feedback* is used in 91% of apps, making it the most frequently used gamification component and game element. *Points* are the second most frequent gamification component and are used by 43% of apps. The use of remaining gamification components falls below 20% of apps. The range for gamification components used in our sample of apps is 1 to 7 (out of 10 possible), with nearly 51% using only one component and only 5% using more than 5. Game elements, other than feedback, drop off to 10% or less of apps. This makes game elements the least used category, with a mean of 1.2 game elements used per app. The range of game elements used varied from 0 to 4 (out of 11 possible), with 74% of apps using only 1 element and 9% using 0 elements. The two most frequently used game elements are also included in the gamification component index variables (i.e., feedback and leaderboard), thus we looked at the correlation between gamification components and game elements, finding a moderate correlation ($r(55) = 0.62$, $p = 0$).

The most commonly used behavioral construct is providing general information in nearly 95% of apps (Fig. 1c). This is slightly higher than the frequency of feedback for gamification components (Fig. 1a) and game elements (Fig. 1b). We note that feedback typically refers to information provided in response to an action by the user, e.g., energy used, miles driven, points collected; whereas general information includes factoids and program or rebate information, as well as some types of feedback (e.g., app points are not general info, but energy use and miles driven are). This overlap explains the similarity in frequency between feedback and general information ('info'). The next two most commonly used constructs are framing in 91% of apps and awareness of consequences in 63% of apps. The remaining constructs are all used by fewer than half of apps, with subjective norms and mental accounting used the least often. Apps include a mean of 4.4 behavioral constructs, ranging from 1 to a maximum of 8 (out of 13 possible constructs), indicating that developers are underutilizing behavioral science in app design. Only 21% of apps used more than 5 behavioral constructs.

Finally, we regressed the number of reviews and app rating on the following independent variables: number of behavioral constructs used, number of gamification components used, number of game design elements used, integrated device(s) used (yes/no), and year of first development. Year of first development was the only statistically significant predictor ($b = -16.3$, $t(50) = -2.95$, $p = .005$)[1] of the number of reviews after removing the SunPower app (n = 666), which is an outlier for number of reviews (*adj.* $R^2 = 0.11$, $F(5, 50) = 2.37$, $p = .05$). The negative coefficient indicates that the earlier an app was released the more reviews it will have, which is an expected relationship. This suggests that, over time, the general group of energy apps are gaining popularity (to the extent captured by the number of reviews received).

For app rating, neither year of first development (p = 0.14) nor number of reviews (p = 0.12) were significant predictors, nor did they improve model fit, thus they were removed from subsequent models. Note that because 22 apps received no rating the final sample size for the models with app rating as the dependent variable was n = 35. Table 2 shows regression models for app rating. The gamification components (GC) index variable is consistently a significant predictor and the only significant predictor ($b = 0.342$, *adj.* $R^2 = 0.34$, $F(1, 33) = 18.17$, $p = .0002$) of app rating. Game elements when modeled alone are moderately significant ($p < 0.1$); however, lower explained proportion of variance (*adj.* $R^2 = 0.08$) indicates that gamification components are a significantly better predictor of app rating. Thus, gamification components have greater explanatory power, though we do not know if this is related to a specific component, a particular combination or subset of components, or the use of more components in general (i.e., more components regardless of which ones). A larger sample that includes apps using more overall and more combinations of gamification components and game elements would be needed to tease out the full picture of how the inclusion of individual components and elements and combinations of certain components and elements impact app rating. Such an analysis, though desirable, is not feasible at this time, since the energy apps space is still relatively limited.

[1] b is the regression coefficient, t-test, and degrees of freedom in parentheses.

Table 2
Regression models for app rating as the dependent variable and behavioral constructs, gamification components, game elements, and device. Standard error in parentheses.

	App Rating					
	(1)	(2)	(3)	(4)	(5)	(6)
GC	0.333***	0.340***	0.328****	0.342****		
	(0.107)	(0.105)	(0.080)	(0.080)		
GE	−0.052	−0.039			0.389*	
	(0.218)	(0.214)			(0.194)	
BC	0.096	0.091	0.093			0.137
	(0.080)	(0.079)	(0.077)			(0.093)
device	−0.150					
	(0.283)					
Constant	2.136****	2.050****	2.020****	2.385****	2.696****	2.603****
	(0.452)	(0.417)	(0.378)	(0.230)	(0.289)	(0.425)
Observations	35	35	35	35	35	35
R^2	0.390	0.384	0.383	0.355	0.109	0.062
Adj. R^2	0.308	0.324	0.345	0.336	0.082	0.034
Residual Std. Error	0.801 (df = 30)	0.792 (df = 31)	0.780 (df = 32)	0.785 (df = 33)	0.923 (df = 33)	0.947 (df = 33)
F Statistic	4.791***(df = 4; 30)	6.443*** (df = 3; 31)	9.948****(df = 2; 32)	18.170**** (df = 1; 33)	4.034* (df = 1; 33)	2.188 (df = 1; 33)

Note: *p < 0.1.
**p < 0.05.
***p < 0.01.
****p < 0.001.

4. Discussion

We identified 57 apps meeting the inclusion criteria, which we specified as apps that use at least one gamification component and target direct energy use behaviors (such as energy efficiency and conservation behavior, solar energy, home energy efficiency upgrades, and efficient transportation). We note that one limitation of this study is that we used the U.S. Apple App Store, and thus our findings have a U.S. bias. However, given that reviews of gamification found few examples meeting the standards of their inclusion criteria regardless of geography, we anticipate that app developers outside of the US face similar challenges and that the methodology, if not the results, are applicable outside of the U.S.

Overall, we find that app ratings increase with the number of gamification components included by the designers. We find that gamification components are used more frequently in apps and account for a greater proportion of variance in app ratings than game design elements. Additionally, the majority of apps do not consistently deploy behavioral constructs identified in the literature as being successful in behavior change interventions. Unexpectedly, the use of behavioral constructs was not a statistically significant predictor of app rating.

While more behavioral constructs were included in the apps on average compared to gamification components and game elements, these did not correlate with higher app rating. These constructs are identified in the literature as positively associated with successful behavior change interventions in the domain of energy use; thus, the inclusion of more behavioral constructs would presumably lead to more successful apps in terms behavior change outcomes, not necessarily a more enjoyable app experience. Since we do not have data on behavior change outcomes resulting from the use of these apps, our study is limited in drawing conclusions on the role of behavioral constructs in the success of energy-related apps in affecting intended outcomes. Furthermore, the combination of elements is varied and app goals are vaguely defined and highly variable, making it unclear whether outcomes would provide conclusive information for comparison across the energy sector. Thus, we rely on the literature regarding pro-environmental and energy behavior change and gamification discussed above.

We found that none of the apps used a complete set of the behavioral constructs belonging to a single behavioral theory or framework (see Table 1), though seven of the apps did include both general information and external context, the constructs identified for utility maximization theory. However, these two constructs are only the behavior related components of the theory, which relies most heavily on rational evaluation of information and use of limited resources (i.e., the behavioral constructs alone do not fully account for the theory). Thus, none of the apps presented a robust design targeting behavior change, which potentially limits the effectiveness of the app design in achieving the intended outcomes given that the theories and frameworks listed are designed around complementary and moderating constructs. This also suggests a gap between the (energy-app design) practitioner and (energy behavior change) academic communities. Future research focusing on the behavioral *outcomes* of apps and how they relate to the inclusion of behavioral constructs would be of great value in designing effective apps. Specifically, determining if outcomes are related to the total number of constructs or inclusion of the complete set of constructs included for a given theory would be particularly informative for app design practice. An improved understanding of how behavioral constructs influence outcomes combined with the above insights on the use of gamification components and game elements in app design will enable the creation of apps that are both efficacious and well received by users.

In comparison to Lister et al.'s assessment of health-related apps, the energy apps analyzed in this paper used fewer game components, game elements, and behavioral constructs than the health-related apps [25]. This was particularly pronounced in regards to game elements, where the least used game elements (3-D environments and story/narrative) were still used in 6% of health apps. The only game element where energy apps outperformed health apps was in using feedback (91% of energy apps and 34–58% of health apps). Direct comparison with gamification components and behavior constructs are difficult due to differing definitions between the two studies; however, the health apps used more of the constructs in greater percentages with the exception of feedback and general information. This is in contrast to Edwards et al. who found feedback to be used in 94% of the health apps they reviewed, similar to the percentage we found [26]. They used a different taxonomy of behavioral change techniques that do not map directly to our study, but they found overall that apps used an average of 14 different techniques, much higher than what we find for the energy apps in our study. Additionally, consistent with our findings, they found no correlation between customer rating and number of behavior change techniques, indicating that this relationship may be robust across application domains (health and energy, in this case).

5. Conclusion

After screening for the inclusion criteria (i.e., target direct energy use behaviors and use at least one gamification component), we found 57 energy-related apps using gamification, covering behavioral goals including reducing energy usage, reducing transportation miles, and adopting solar energy. We found that the majority of apps use only one gamification component and the use of gamification components was the only significant predictor of app rating; the use of game elements has minimal positive impact on app rating; and the use of behavioral constructs does not improve app rating. These findings and our experience collecting the dataset lead to three recommendations for energy app designers.

Our first recommendation is to improve discoverability. We used 22 training apps to reverse engineer the keywords used by app developers to list their apps on the Apple App Store, resulting in an average rank (i.e., the list location of the app when searching the keyword on the App Store) of 37. This low position on the search result list indicates that energy-related apps do not make good use of SEO in keyword selection. Currently, it is easier (and more effective) to web-search for energy-related apps first rather than beginning the search in the App Store itself, followed by searching for specific app titles on the App Store. However, the google search results still only returned a limited set of apps, so increased marketing budgets are also called for to increase the searchability and visibility of energy apps. Finally, cross-promotion with utility energy programs or related products (e.g., solar panels or home automation products) would also increase potential user awareness of the apps. Thus, app developers should improve keyword SEO, increase marketing budgets, and use cross-promotion to make apps easier to find for casual potential users. Additionally, the creation of a top or near-top level category analogous to the extant "health and fitness" category for health-related apps would increase discoverability for interested consumers to browse energy-related apps.

Second, we recommend increased use of gamification components and game design elements. We find that user app ratings increase with increased use of gamification components; however, with an average of only 2.1 components used in an app (out of a potential 10 components), gamification components are not widely or extensively used by app developers. For those app developers seeking to create a more hedonic experience in their apps, careful attention to gamification and the more sophisticated elements of game design is warranted as these can make the app experience more fun, engaging, and intrinsically rewarding [39–41].

Third, improving integrated design and use of best practices could improve user experience. The overall relationship between more gamification components and higher app ratings may be related to users finding them more fun or engaging, a correlation between component use and greater overall attention to better app design, or a combination of the two. As noted before, the design of this study does not allow us to discern between these effects. Additionally, none of the apps in our sample used the full suite of gamification components. The positive relationship between component use and app rating could possibly turn negative at a relatively higher number of components, due to overly complex or tedious design. Alternatively, this relationship could flatten out or continue increasing, indicating an avenue for future study with a sample of apps that include more gamification components (when such apps become available on the App Store). Thus, while app developers should consider integrating more gamification components into their designs, these components should be used where they make an appropriate and considered contribution to the design and not just for the sake of inclusion.

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Appendix A. Supplementary data

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